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THE EFFECTIVENESS OF REDUNDANT COLOR-CODING ON SEARCH AND IDENTIFICATION IN A PROCESS-CONTROL TASK

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Abstract

This study investigated the effectiveness of redundant color-codes and monochrome shape-codes for coding the operational states of scanpoints displayed on a CRT-displayed process-control diagram. Response-times were faster with color-coding than with shape-coding, and this relationship generally held true across all levels of display density and inspection load, with both search and identification tasks. Also, color-coding mitigated the detrimental effects of increased density and load. Coding did not affect response-accuracy on the search task, but on the identification task more errors were produced with shape-coding. Although density and load had no effect on accuracy in the identification task, maximal density and load reduced accuracy in the search task. In terms of subjective preference, color-coding was superior to shape-coding on a wide range of variables. It was concluded that redundant color-coding was superior to monochrome shape-coding given the present task conditions, but that the decision to choose color over other attributes should be based upon a consideration of operator requirements and display parameters.

Introduction

The relatively recent development in color-graphics cathode ray-tube (CRT) displays has reawakened an interest in the effectiveness of color as a means of coding information. A major concern is whether redundant color-coding is more beneficial than shape-coding in terms of efficient performance, and whether the potential advantage outweighs the cost of implementing color-graphics (1). Redundant color-coding refers to cases where targets are equally identifiable in terms of color or shape (i.e., color and shape are perfectly correlated). With nonredundant color-coding, on the other hand, targets can be identified in terms of color only or shape only. In other words, knowing the color of the target reduces uncertainty but does not enable actual identification.

Christ (2) conducted a comprehensive review of the literature from 1950 to 1973 that examined the effectiveness of color-coding information. The majority of these studies were simple and unrealistic, and used projected or reflected targets rather than CRT-displayed targets. Only three studies were found that used redundant color in identification tasks (where the category of a specified target must be identified), and these showed that the addition of redundant color to brightness, size or digits facilitated absolute identification. A total of 59 experimental comparisons within search tasks (where a target category must be counted or located) showed that redundant color-coding, compared to other coding-schemes, consistently led to quicker response-times (providing the subject knew the color of the target). Also, redundant color-coding was more effective when display density (the number of targets simultaneously displayed) was high and when the number of nontarget colors was increased. Christ (2) concluded that task-type and display conditions were factors that must be taken into account in the assessment of color-coding effectiveness.

All of the studies reviewed by Christ used naive subjects. Christ and Corso (3) and Teichner, Christ and Corso (4), however, used practiced subjects to evaluate the effectiveness

of color-coding and found that practice attenuated any performance differences between color- and achromatic-coding. An important implication of this research is that if short-term enhancement in performance is important and if the operator has little experience, then color coding-schemes may improve performance. On the other hand, if performance over the long-term is of concern, then manipulating color coding-schemes may not serve the purpose.

Only a handful of studies have examined redundant color-coding in complex or multiple-task situations where the operator must allocate his processing resources to several tasks that compete for his attention. For instance, six studies reported that redundant color-coding did not enhance performance. Tasks employed in these studies included an air-traffic control (ATC) simulation (5), a shipboard tactical display simulation (6), identification of engine parameter failures in flight simulation (7), and simulated flight missions (8, 9, 10).

On the other hand, eight studies showed advantages of redundant color for certain aspects of the task. For instance, although color did not enhance prediction of separation rule violations in an ATC task, it enhanced interpretation when symbology overlapped (11). While color did not affect reaction-time for reporting malfunctions, it decreased target detection-time (12). Noble and Sanders (13) reported that when color was a redundant cue, it improved reaction-time to traffic signs. Color aided in the management of stores information in terms of response-time, but not in terms of accuracy (14). Color clearly enhanced performance on a threat-recognition task in a simulated flight mission (15). Using a process-control task, Luder and Barber (16) and Zwaga and Duijnhouwer (17) found that color enhanced search performance. On an identification task, the former study found no benefit of color, while the latter study found that redundant color was actually worse than shape. Finally, MacDonald and Cole (18) evaluated the effectiveness of redundant color-coding in a flight-information display using seven different information processing tasks while subjects simultaneously performed a compensatory tracking-task. Several of these tasks included elements of both search and identification. Color

led to faster response-times and fewer errors in all tasks where relevant information was uniquely coded. Nevertheless, the effectiveness of color-coding could not be predicted by simply classifying tasks in terms of search or identification. The authors concluded that the evaluation of an information display "requires detailed data on the ways in which the displayed information is to be used, since this determines the nature of tasks which users will perform and defines the optimum role of color" (MacDonald and Cole, 1988, p.13).

In summary, the findings on the effectiveness of redundant color-coding are inconsistent and appear to be at least partially dependent upon the interaction of a variety of task variables. Unfortunately, the nature of these interactions has not been identified. Therefore, before deciding whether or not to implement redundant color-coding in an operational setting, it might be best to test its effectiveness with a simulation of the specific operational tasks in question rather than basing a decision upon generalizations from studies using dissimilar tasks.

Many of the earlier studies that have evaluated the effectiveness of redundant color-coding used displays that were unrealistic in that they used projected or reflected targets, and the predictability of the location and frequency of occurrence of these targets was low. Most current operational tasks, however, use more predictable displays where dynamic information is presented against a fixed background, and this information is usually presented on a CRT display. It is therefore important to establish whether past findings are generalizable to more realistic and current displays.

The primary aim of the study was to determine how performance with redundant color-coding (i.e., coding by shape and color) would compare to performance with shape-coding when machinery-control information was displayed on a CRT display in a fixed format. Because it is important to determine the conditions under which these findings hold true, these relationships were examined with search and identification tasks, under different levels of inspection loads (the number of target scanpoints whose states are in question) and display

densities (the number of target scanpoints displayed). Luder and Barber (16) examined the effectiveness of redundant color-coding using a fixed-format display, but they used display densities of only 5 and 9 targets. In order to test the merits of redundant color-coding under more complex and realistic conditions, the present study used considerably greater display densities of 12, 16, and 20 target scanpoints. Second, because the effectiveness of different symbols has not yet been established for machinery-control information, this study also purported to compare the effectiveness of two different sets of shapes under both color and monochrome conditions where: a) codes were differentiated in terms of "filled" geometric shapes and b) codes were differentiated in terms of "hatching" (lines drawn within a hollow square contour).

Method

Subjects

The subjects were twelve, naive, paid volunteers with normal color vision as measured by the H-R-R Pseudoisochromatic Plates, normal visual acuity as measured by Regan's charts, and normal contrast sensitivity as measured by Vistech 6500 contrast sensitivity charts.

Design

The study used a within-subject design and all of the following were within-subject factors: coding scheme (colored "filled" shapes, colored "hatched shapes", monochrome "filled" shapes and monochrome "hatched" shapes), task (identification and search), display density (12, 16, or 20 simultaneously displayed scanpoints), and inspection load (1, 2 or 3 scanpoints whose states were in question). Dependent measures included reaction-time and accuracy for search and identification tasks.

Subjects were tested under four coding conditions that were presented on four different days in a balanced Latin-square design. For each condition, subjects were tested on four blocks of 36 trials. The same set of 144 trials were used for each of the four coding conditions. Trials within

blocks were balanced for equal presentation of each task-type, display density, inspection load, and true/false response so that one observation for each combination was presented per block.

Display

The stimuli were programmed and displayed on a Sun-3/110 color workstation. Subjects were presented with a process-control display containing either 12, 16, or 20 scanpoints, each of which was labeled in alphabetical sequence. Although the position of scanpoints varied slightly across display densities (i.e., with lower density there was a greater separation among scanpoints), alphabetic sequencing was maintainted.

A scanpoint could be in one of three possible states: normal, warning and alarm. Each state was represented by one of the four code-sets as shown in Table 1.

Subjects viewed 6-mm high symbols displayed on the CRT, from a distance of approximately 50 cm, producing a resolution of 39 minutes of arc. The average respective illuminances on the computer keyboard and CRT were 67 lx and 10 lx, and the average background luminance and scanpoint luminance were 0.7 cd/m^2 and 5 cd/m^2, respectively. The display background was black under all coding conditions. Task-irrelevant information that was also presented on the screen was displayed in white, red, and green, in all coding conditions.

Procedure

In order to minimize fatigue and boredom, the four test sessions were conducted on separate days. Owing to subject availability, and an effort to control for the time-interval separating each test session, the first two sessions were conducted on consecutive days, two weeks elapsed, and the last two sessions were conducted on consecutive days. The four sessions were identical except for different coding conditions. Prior to each testing session, subjects rated themselves on various visual symptoms, practiced identifying the states represented by the coded scanpoints, read task instructions, and completed 14 practice computer-trials.

TABLE 1. Normal, Warning and Alarm States as Represented by the Four Coding Conditions

STATES			CODING CONDITION
NORMAL	WARNING	ALARM	
blue interior	yellow interior	red interior	Condition C
white interior	white interior	white interior	Condition S
blue lines	yellow lines	red lines	Condition HC
white lines	white lines	white lines	Condition H

Following training, subjects underwent four blocks of 36 trials, for a total of 144 trials. On a given trial, a statement was displayed at the bottom of the CRT display simultaneously with a computer-generated auditory tone. After the statement was read and understood, the subject pressed the spacebar which terminated the statement and displayed the diagram. The subject then indicated whether the statement was true or false by pressing the "t" or "f" key respectively, which terminated the diagram. Trials were separated by an interval of five seconds. Subjects were instructed to work as quickly and as accurately as possible.

The search task, which was similar to a counting task, was characterized by a statement such as, "There are three scanpoints in alarm." The identification task, on the other hand, was less general in that subjects were required to identify the state of specific scanpoints on the basis of their alphabetical label in order to respond to the statement. A characteristic statement would be, "Scanpoints C and D are in alarm."

"Inspection load" refers to the number of scanpoints whose states were in question. Each statement involved either one, two or three scanpoints depending upon the level of inspection load. The scanpoints that were to become targets on a given trial were randomly selected from a pool of either 12, 16, or 20 scanpoints, depending upon the density condition. Since the normal state was considered the default state, only states of alarm and warning were included in the statements. The state (warning or alarm) mentioned in the statement were randomly selected with the restriction that within each block, there was an equal number of statements referring to each of these states.

Two measures were recorded: a) the accuracy of true and false responses, and b) the time required to respond to the search and identification statements (determined by the interval between pressing the spacebar and the true or false key).

At the end of their final testing session, subjects completed a 20-point rating scale to elicit subjective evaluations of the four coding conditions on each of the following 14 variables:

legibility, aesthetic appeal, prolonged use, ease of use, satisfaction, stimulation, discriminability, effort, motivation, mental fatigue, visual discomfort, frustration, perceived accuracy and perceived reaction-time.

Results

The present study involved a completely within-subject design with the following included as within-subject factors in an analysis of variance (ANOVA): coding condition (color, C; shape, S; hatch, H; hatch/color, HC), task (search, identification), density (12,16,20), load (1,2,3), and subject (12). Each combination of the first four factors was averaged over two trials (one requiring a "true" response and one requiring a "false" response). Because the effect of block was of no interest, it was not included as a factor in the ANOVA. All post-hoc tests were Tukey tests at the 0.05 level of significance.

Response Time (msec)

The response times (RTs) corresponding to incorrect responses were not included in the RT analyses. Significant main effects of code $F(3,33)=21.02$, $p<0.0001$, task, $F(1,11)=58.21$, $p<0.0001$, density, $F(2,22)=61.30$, $p<0.0001$, and load $F(2,22)=157.91$, $p<0.0001$, were found. Post-hoc Tukey tests showed that RT was faster under Conditions C and HC compared to Conditions S and H, and faster with the search than the identification task. RT increased with increasing density and with increasing load.

Significant interactions were found for Code X Density, $F(6,66)=10.06$, $p<0.0001$ and for Code X Load X Task, $F(6,66)=11.88$, $p<0.0001$. These interactions will be discussed below.

Code X Density. As can be seen in Figure 1, RTs were faster with Conditions C and HC than with Conditions H and S under all levels of density. Furthermore, increasing density had a detrimental effect only for the monochrome conditions.

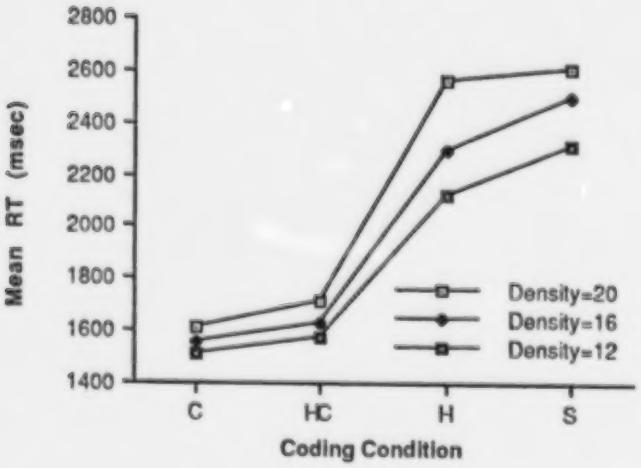

Figure 1. Mean RT as a function of code and density.

Code X Load X Task (see Figures 2 and 3). Conditions C and HC consistently led to quicker responses compared to Conditions H and S across all tasks and loads. The effect of increasing load on RT was more apparent in the monochrome conditions than in the color conditions, and the effect of load on RT under the color conditions was more pronounced with the identification task than with the search task.

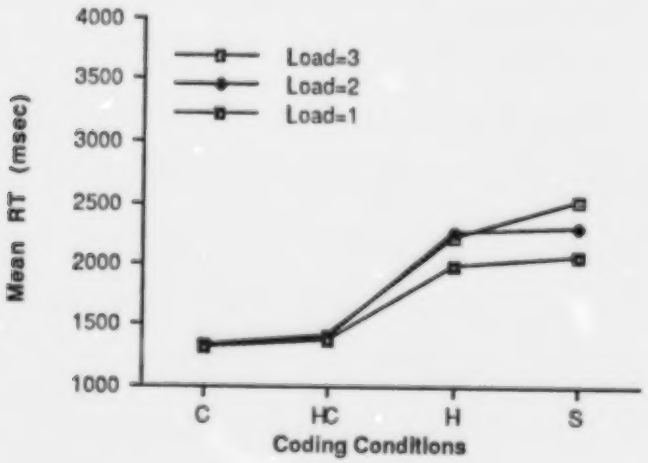

Figure 2. Mean RT as a function of code and load for search.

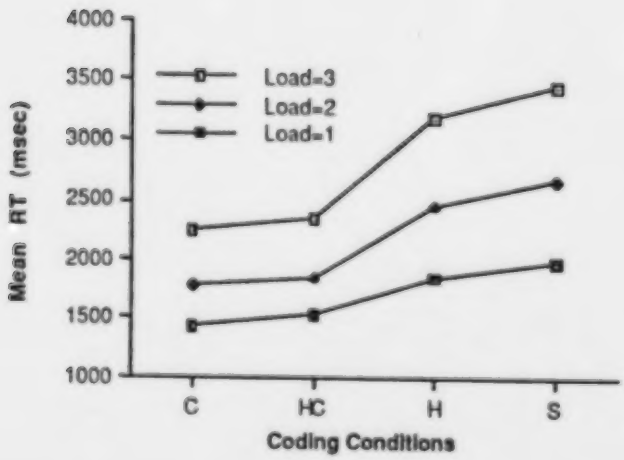

Figure 3. Mean RT as a function of code and load for identification.

Accuracy

From the ANOVA performed on the number of correct true/false responses, significant main effects were found for code, $F(3,33)=5.45$, $p<.004$; density, $F(2,22)=21.78$, $p<0.0001$ and load, $F(2,22)=6,93$, $p<0.005$. There were more correct responses with Conditions C, HC, and H, than with Condition S, more correct responses with densities of 12 and 16 compared to a density of 20 , and more correct responses with loads of 1 and 2 than with a load of 3. There were no differences due to task.

A significant interaction was found for Code X Task, $F(3,33)=4.29$, $p<0.01$. As shown in Figure 4, Conditions C, HC, and H led to more correct responses than Condition S with the identification task. With the search task, however, there were no differences due to coding.

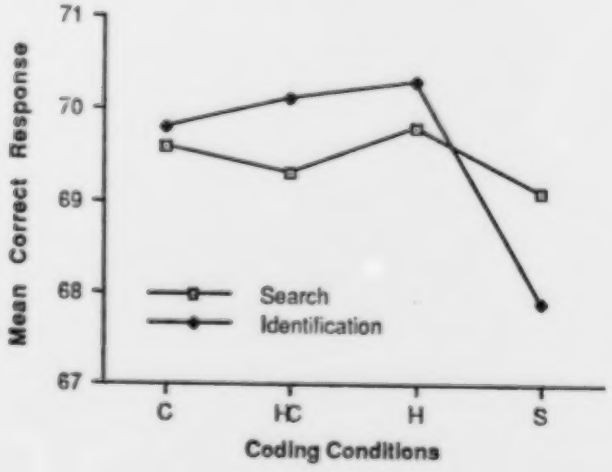

Figure 4. Mean number of correct responses as a function of code and task.

Because four-way interactions were of no theoretical interest, and are statistically questionable (extremely large degrees of freedom), they were not reported here.

A Pearson-moment correlation between response-time and accuracy measures revealed a significant inverse relationship, $r(6910)= -.045$, $p<.0002$. However, this relationship was too weak to argue for a speed-accuracy trade-off.

Subjective Comparisons of Coding Conditions

At the end of their final testing session, subjects completed rating scales to compare their subjective evaluations of the four code-sets on 14 different variables. A within-subject, one-way ANOVA on Code showed a significant main effect of code for each of the 14 variables. A summary of the results is as follows: Color-coding conditions (C and HC) were more highly rated than shape-coding conditions (S and H) for legibility, aesthetic appeal, prolonged use, ease of use, satisfaction, stimulation and discriminability. Conditions S and H received higher scores than Conditions C and HC for expended effort, mental fatigue, visual discomfort and frustration. Subjects believed that Conditions C and HC led to quicker RT and accuracy than Condition S, and that Condition C led to better accuracy than Condition H. Finally, subjects felt more motivated to perform the task under Condition C than under Condition S.

Discussion

The results clearly showed that redundant color-coding led to faster RTs compared to monochrome shape-coding and that neither Conditions C and HC nor Conditions S and H differed from one another. Although the two types of coding shapes were quite different from one another ("filled" versus "hatched" shapes), they did not differentially affect performance. Furthermore, it is important to note that these relationships generally held true across all display densities, inspection loads, and under both search and identification tasks.

The finding that redundant color-coding improved RT on the identification task is in line with MacDonald and Cole (18), but counter to Luder and Barber (16) who found no effect of redundant color. Among the studies reviewed by Christ (2), only three used redundant color-coding with an identification task. Although Christ (2) reported that redundant color was advantageous, statistical significance was attained in only one (19) of the three studies. It should be emphasized, however, that these studies compared redundant color only to brightness and size, but not to shape.

The inconsistency between the present finding and Luder and Barber's (16) may be due to the fact that their search and identification tasks were actually secondary tasks performed while simultaneously engaged in a primary tracking task. Thus, it is not surprising that performance would differ between conditions requiring full attention to those of divided attention. Furthermore, Luder and Barber used lower display densities (5 and 9 targets) than the present study (12, 16 and 20 targets), and it is possible that effects of redundant color-coding are not generalizable across all display densities.

Studies have consistently attested that search-time increases as display density increases (15, 20, 21, 22, 23, 24, 25, 26, 27). The densities employed in these studies have generally ranged from 20 to 100 stimuli, with the exception of Bundesen and Pedersen (27) who employed densities of nine, 17 and 25 stimuli. Furthermore, as noted by Christ (2), the benefit of redundant color-coding generally increased under higher display densities.

In line with the literature, the present study showed that redundant color-coding maintained its superiority over all three density levels. Although RT generally became slower as density increased, the detrimental effect was less pronounced with redundant color-coding than with shape-coding.

With the identification task, RT increased with each increment of load under all coding conditions, but the detrimental effect of increased load was minimized in the color conditions (C and HC). With the search task, however, RT increased with increasing load except in Condition C. In brief, redundant color-coding conditions mitigated the deleterious effects of increased inspection load, particularly in the search task. It is not clear why load affected RT with Condition C in the identification task but not in the search task. Presumably it is because the search task was less difficult than the identification task, and the benefits of color outweighed the effects of increasing load on the simpler task.

Effects on accuracy measures differed considerably from those on RT measures. With the

search task there were no code differences, but with the identification task more errors were produced in Condition S. An interesting finding was that density and load did not affect accuracy with the identification task, but had very pronounced effects with the search task. More specifically, with the search task, more errors occurred at the highest inspection load (3 compared to 1 and 2) and highest display density (20 compared to 12 and 16). At first glance this appears to be counterintuitive because one would expect the effects of high load and density to be more detrimental with the more difficult task, the identification task. However with the identification task, subjects first located the scanpoints' letter label and then examined its corresponding scanpoint. Consequently, scanpoints were probably given closer scrutiny in the identification task than in the search task, particularly when the subject was under the higher workload conditions, and this is manifested itself by a greater degree of accuracy in the identification task. Evidence for a speed-accuracy trade-off argument is not particularly convincing, however. The evidence that would be required to support such an argument is that RT be faster with the search than the identification task under a load of 3 and a density of 20. The actual findings were that RT was in fact faster in the search and identification tasks under a load of 3 and density of 20, but also under a load of 2 and densities of 12 and 16. For this reason, coupled with the fact that the correlational data revealed only an extremely weak inverse relationship between speed and accuracy, one cannot argue for a speed-accuracy trade-off.

Generally speaking, the color codes (C and HC) were preferred over the monochrome codes (H and S) in a number of respects and these ratings corresponded highly with subjects' performance. Subjective ratings of RT performance were consistent with objective measures but the correspondence between subjective and objective measures was less consistent for response-accuracy.

Justification to use color as an information code in visual displays is frequently based upon

subjective preference although it does not always lead to superior performance (8, 9, 28, 29). This argument, however, remains to be tested. Furthermore, because subjective evaluations are not always in line with objective measures, it is not clear whether they should be given serious consideration in the evaluation of color displays.

In summary, this study has clearly demonstrated that redundant color-coding was more effective than monochrome shape-coding in the successful execution of a CRT-displayed process-control task. The evidence that substantiates this conclusion is as follows: Color-coding conditions led to quicker RTs than shape-coding conditions, and this was true with both search and identification tasks; color-coding mitigated the detrimental effects of increased display density on RT measures; color-coding mitigated the detrimental effects of load on RT with both the identification and the search tasks but particularly with the search task; color-coding led to fewer errors on the identification task but had no effect on the search task; subjective measures of coding effectiveness corresponded quite closely to objective measures in that subjects consistently preferred redundant color-coding over shape-coding.

Although color-coding may be beneficial in visual displays in terms of enhancing operator performance, it may also introduce other system considerations such as increased maintenance costs, new criteria for operator-selection, and changes in system reliability (1). Thus, before decisions are made to implement color displays in operational environments, investigations of possible improvements in operator performance are required to justify the increased cost.

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References

1. Christ, R.E. (1983). Research for evaluating visual display codes: an emphasis on colour coding. In F. Easterby and H. Zwaga (Eds.), Information Design. Chichester, U.K.: John Wiley.

2. Christ, R.E. (1975). Review and analysis of color coding research for visual displays. Human Factors, 17, 542-570.

3. Christ, R.E., and Corso, G.M. (1975). Color research for visual displays (Report No. ONR-CR-213-102-3). Arlington, Virginia: Office of Naval Research.

4. Teichner, W.H., Christ, R.E., and Corso, G.M. (1977). Color research for visual displays (Report No. ONR-CR-213-102-4F). Arlington, Virginia: Office of Naval Research.

5. Christ, R.E., and Corso, G.M. (1983). The effects of extended practice on the evaluation of visual display codes. Human Factors, 25, 71-84.

6. Hessling, U. (1984). Shape with and without redundant color as a coding mechanism for simulated radar displays in a time-extended simple vigilance task. Unpublished master's thesis, Naval Postgraduate School, Monterey, California.

7. Calhoun, G.L., and Herron, S. (1981). Computer generated cockpit engine displays. In Proceedings of the Human Factors Society, 25th Annual Meeting. Santa Monica, CA: Human Factors Society.

8. McCully, M.S. (1984). Effects of alternative chromatic mixed graphics displays in decision support systems (Report No. AFIT/IC/NR-84-46D). Air Force Institute of Technology, Wright-Patterson AFB.

9. Martin, R.L., and Way, T.C. (1987). Pictorial format for two-seat fighter-attack aircraft. In Proceedings of the Human Factors Society, 31th Annual Meeting. Santa Monica, CA: Human Factors Society.

10. Zenyuh, J.P., Reising, J.M., and McClain, J.E. (1987). Advanced head-up display (HUD) symbology: aiding unusual attitude recovery. In Proceedings of the Human Factors Society, 31th Annual Meeting. Santa Monica, CA: Human Factors Society.

11. Connolly, D.W., Spanier, G., and Champion, F. (1975). Color display evaluation for air traffic control (Report No.FAA-RD-75-39). Washington, DC: U.S. Department of Transportation, Federal Aviation Administration.

12. Wagner, D.W. (1977). Experiments with color coding on television (Report No. NWC-TP-5952. China Lake, California: Naval Weapons Center.

13. Noble, M., and Sanders, A.F. (1980). Searching for traffic signals while engaged in compensatory tracking. Human Factors, 22, 89-102.

14. Aretz, A.J., and Calhoun, G.L. (1982). Computer-generated pictorial stores management displays for fighter aircraft. In Proceedings of the Human Factors Society, 26th Annual Meeting . Santa Monica, CA: Human Factors Society.

15. Kopala, C.J. (1979). The use of color-coded symbols in a highly dense situation display. In Proceedings of the Human Factors Society, 23th Annual Meeting. Santa Monica, CA: Human Factors Society.

16. Luder, C.B., and Barber, P. (1984). Redundant color coding on airborne CRT displays. Human Factors, 26, 19-32.

17. Zwaga, H.J.G., and Duijnhouwer, F. (1984). The influence of a fixed background in a VDU display on the efficiency of colour and shape coding. In C.P. Gibson (Ed.), Proceedings of NATO Workshop "Color coded versus monochrome electronic displays, "Farnborough, England.

18. MacDonald, W.A., and Cole, B.L. (1988). Evaluating the role of colour in a flight information cockpit display. Ergonomics, 1, 13-37.

19. Eriksen, C.W., and Hake, H.W. (1955). Multidimensional stimulus differences and

accuracy of discrimination. Journal of Experimental Psychology, 50, 153-160.

20. Green, B.F., and Anderson, L.K. (1956). Color coding in a visual search task. Journal of Experimental Psychology, 51, 19-24.

21. Green, B.F., McGill, T., and Jenkins, W. (1953). The time required to search for numbers on large visual displays (Report No. TR-36 AF19-(122)-458). Lexington, Massachucettes: Massachusettes Institute of Technology, Lincoln Laboratory.

22. Smith, S.L. (1962). Color coding and visual search. Journal of Experimental Psychology, 64, 434-440.

23. Smith, S.L. (1963). Color coding and visual separability in information displays. Journal of Applied Psychology, 47, 358-364.

24. Smith, S.L., and Thomas, D.W. (1964) Color versus shape coding in information displays. Journal of Applied Psychology, 48, 137-146.

25. Smith, S.L., Farquhar, B.B., and Thomas, D.W. (1965). Color coding in formatted displays. Journal of Applied Psychology, 49, 393-398.

26. Carter, R.C. (1982). Visual search with color. Journal of Experimental Psychology: Human Perception and Performance, 8, 127-136.

27. Bundesen, C., and Pedersen, L.F. (1983). Color segregation and visual search. Perception and Psychophysics, 33, 487-493.

28. Chase, W.D. (1970). Evaluation of several TV display system configurations for visual simulation of the landing approach. IEEE Transactions on Man-Made Systems, MMS-11, 140-149.

29. Greenstein, J.S., and Fleming, R.A. (1984). The use of color in command control electronic status boards. In C.P. Gibson (Ed.), Proceedings of NATO Workshop "Color coded versus monochrome electronic displays", Farnborough, England.

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This study investigated the effectiveness of redundant color-codes and monochrome shape-codes for coding the operational states of scanpoints displayed on a CRT-displayed process-control diagram. Response-times were faster with color-coding than with shape-coding, and this relationship generally held true across all levels of display density and inspection load, with both search and identification tasks. Also, color-coding mitigated the detrimental effects of increased density and load. Coding did not affect response-accuracy on the search task, but on the identification task more errors were produced with shape-coding. Although density and load had no effect on accuracy in the identification task, maximal density and load reduced accuracy in the search task. In terms of subjective preference, color-coding was superior to shape-coding on a wide range of variables, and resulted in fewer frontal headaches following computer trials. It was concluded that redundant color-coding was superior to monochrome shape-coding given the present task conditions, but that the decision to choose color over other attributes should be based upon a consideration of operator requirements, illumination factors and display parameters.

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redundant color-coding

identification

search

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